PURDUE UNIVERSITY | Agricultural and Biological Engineering

CAPSTONE/SENIOR DESIGN EXPERIENCE 2022

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Title: Agricultural Mulch Film

Executive Summary:

The Soybean Innovation Competition is an opportunity for students to practice their creativeness and project planning to bring out new or improved products out of soybean materials. The competition has several specific requirements such that the developed product must use soybean or any of its elements as a crucial component in the product prototype design since the hosts of this competition are the soybean farmers who wish to expand their soybean market; the product idea must also be novel and innovative; limitation of on hundred dollars is the external budget for any cost besides the material package provided by the competition. Considering these requirements, soybean-based agricultural mulch films were chosen by the team to participate in this competition.

1. Background

- Replace compostable plastic agricultural mulch film
- Agricultural film made from 99.5% soy by weight
- Basic functionalities of mulch film
  - Retaining moisture and temperature
- Improve plant and soil health during degradation
- 100% biodegradable
  - Eliminates need for removal of the film after each growing cycle
- Polymerized soy protein isolate base
  - Determines elasticity and ductility
- Fortified grid structure by soy fibers
  - Fibers provides structural and mechanical integrity
- Enriched with soybean meal fertilizer
  - Enriches soil during degradation.
- Composition ratio of fiber and protein determines degradation time and mechanical properties
  - Composition of Silm can be tailored for targeted crops.

2. Problem Statement

Conventional Films

- Made with polyethylene plastics
  - Cheap
- Require removal after each use
  - Increased operational cost
- Leave residues in forms of microplastics
  - Harmful effect on microorganisms in soil

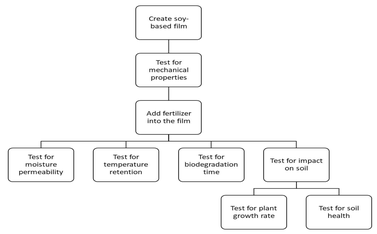
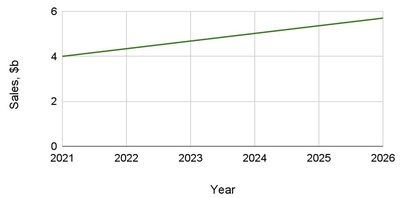


Figure 1: Flowchart of experimental process planning

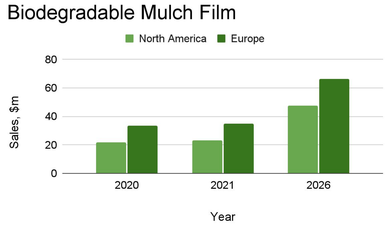
3. Economic Analysis

- Agricultural mulch film market
  - $4b in 2021, projected to grow to $5.7b
  - Compound Annual Growth Rate (CAGR) of 7.8%
  - Most revenue from Pacific-Asia and North America
- Biodegradable mulch film market
  - $71.6m in 2020, projected to grow to $155.2m by 2026
  - Compound Annual Growth Rate (CAGR) of 15.5%
  - Most revenue from Europe and North America
- Our customer group
  - Mostly of vegetable growers and fruit growers
    - Need more water and temperature retention
  - Primary customers are Indiana farmers growing tomatoes and melons
  - 7,867 acres of tomatoes harvested annually
  - 6,600 acres of melons harvested annually
- Target Costs
  - Manufacturing cost: $174 per roll
  - Selling price: $289 per roll
  - Target price within the range of biodegradable mulch films currently in the market
  - Projected a market share of 1.0%
    - Revenue by 2026: $57.0m
  - 76k tons of soybean sale
    - Soybean usage revenue for sponsor: $47.69m
  - Potential for crop-specific mulch films increase revenue
  - Potential to grow customer base in Indiana and expand to North America.

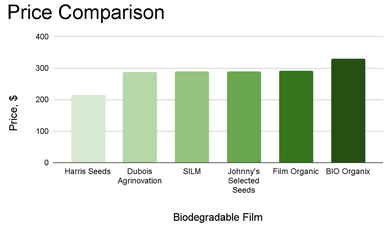
Mulch Film Industry



Biodegradable Mulch Film



Price Comparison



4. Technical Analysis:

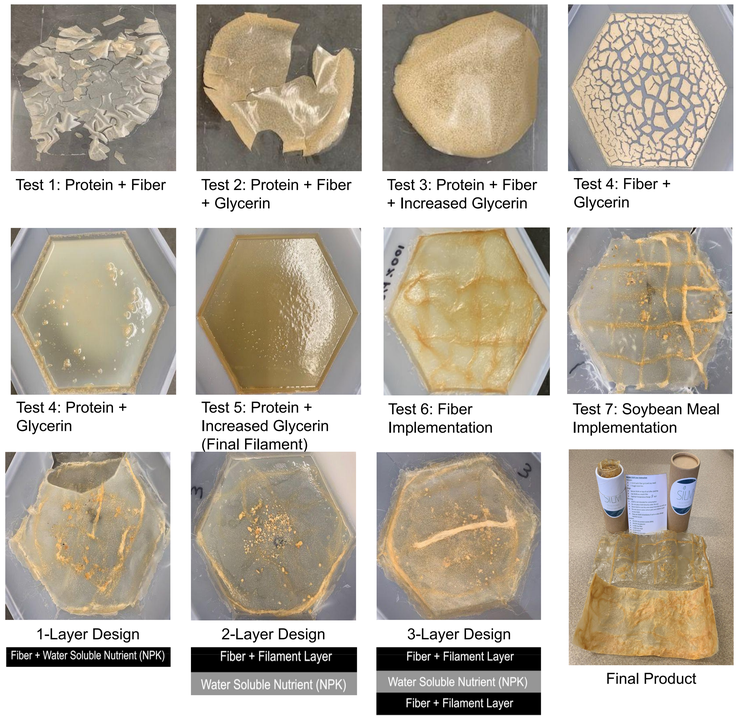
- Stage 1 (tests 1 - 5): Determination of the films filament composition
  - Test 1: Protein and fiber crosslinking with NaOH and succinic acid
  - Test 2, 3: Glycerin for film flexibility
  - Test 4: Protein with glycerin, fiber with glycerin alone
    - Protein and glycerin: very flexible
    - Fiber and glycerin: very brittle
  - Test 5: Optimization of protein and glycerin composition
- Stage 2 (test 6): Implement soybean hairlike fiber into film for structural stability
- Stage 3 (test 7): Implement soybean meal fertilizer into film.

Alternative Solutions and Evaluations

- Stage 4: Creation of three different prototypes
  - 1-layer: Mix the soybean meal into solution before dehydration
  - 2-layer: Layer soybean meal on one side during dehydration
  - 3-layer: Sandwich soybean meal between two filaments
    - 1-layer and 2-layer designs are similar and easy to create in a lab setting
    - 3-layer design is easier to mass manufacture using reinforced plastic extrusion lines.

Final Design and Qualification Analysis

- Structural integrity: Tensile strength tester
  - 38 N, 0.01 GPA
    - Fiber within the film to snaps but filament remains intact
- Water submersion: Submerged under water for 6 hours
  - Remained structurally viable
  - Ripped similar to cardboard with force applied
- Environmental impact
  - Soybean protein: Degrades in 1 month and provides organic nitrogen
  - Soybean fiber: Degrades in 6 months, provides moisture retention, and soil structure
  - Soybean glycerin: Helps metabolism of nitrogen fixing bacteria
  - Soybean meal: Commonly used fertilizer
  - NaOH: Increases soil structural stability
  - Succinic acid: Key promoter of the Krebs cycle, and often used in food and pharmaceutical applications.



5. Impact and Sustainability

- Film residues might remain with harvested crop if not completely degraded
- Accidentally consumption for animals and humans
  - Non-toxic to soil and plant but effects of it on human and animals needs further research
- Smooth surface faced up, and rougher surface faced down
  - Releases nutrients to soil at an earlier stage
- Store film in humid environment away from direct sunlight
  - Reduces the degradation process starting
- Innovative product requires convincing consumers to switch from conventional films.

6. Design and Project Assessment Future Work

Design Assessment

- Common functionalities of conventional film
  - Retains moisture and temperature
- Provides additional nutrients while degrading
  - Improves soil health and plant growth
- 100% biodegradable
- Reduces manual labor cost for removal and fertilizer cost
- Innovative design with wide range of applications
  - Different formulation used for plastic alternatives
- Performs best in temperature between 32° F - 86°F

Future work

- Automation can make the film thinner, stronger, denser
  - Less manufacturing cost compared to PE
- Different colors for different crops, weather conditions, and weed suppression

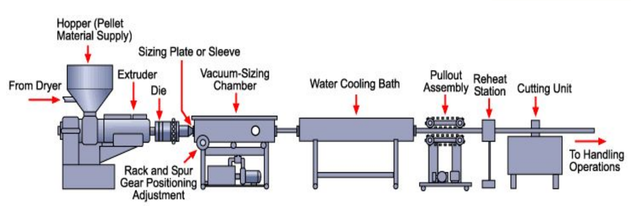


Figure 2: Mass manufacturing process for plastic extrusion line

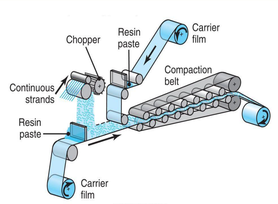


Figure 3: Reinforced plastic extrusion line

Standards Used:
ASTM D5338-15, ASTM 6400, 7 CFR Part 2902, ISO 23517, AENOR UNE-EN 17033

Sponsor:
Indiana Soybean Alliance

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